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The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming ☆

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ABSTRACT

Improvements in technology have made it profitable to tap unconventional gas reservoirs in relatively impermeable shale and sandstone deposits, which are spread throughout the U.S., mostly in rural areas. Proponents of gas drilling point to the activity's local economic benefits yet no empirical studies have systematically documented the magnitude or distribution of economic gains. I estimate these gains for counties in Colorado, Texas, and Wyoming, three states where natural gas production expanded substantially since the late 1990s. I find that a large increase in the value of gas production caused modest increases in employment, wage and salary income, and median household income. The results suggest that each million dollars in gas production created 2.35 jobs in the county of production, which led to an annualized increase in employment that was 1.5% of the pre-boom level for the average gas boom county. Comparisons show that ex-ante estimates of the number of jobs created by developing the Fayetteville and Marcellus shale gas formations may have been too large.

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1. Introduction

Improvements in drilling technology have made it profitable to exploit unconventional gas reservoirs in relatively impermeable media. In part because of the greater feasibility of tapping these new reservoirs through hydraulic fracturing – shooting a mix of water and chemicals into the formation – the Potential Gas Committee recently increased its estimate of gas reserves in the U.S. by 35%, the largest increase in the 44 year history of the committee's report (Colorado School of Mines, 2009). Long term projections of high energy prices suggest that the natural gas industry will have a persistent and growing influence on the economy in the many areas of the U.S. with large gas reservoirs.[1]

Substantial gas exploration is occurring in Pennsylvania (Marcellus Shale Formation) and production has already spiked in Arkansas (Fayetteville Shale Formation) where gas production increased by 2.5 times from 2007 to 2009 (Energy Information Agency, 2011). Growth is expected to continue with Chevron, Exxon Mobile, and Royal Dutch Shell investing heavily in developing the Marcellus Shale (Kaplan, 2010). The trends emerging in Pennsylvania and Arkansas started earlier and are more mature in Colorado, Texas, and Wyoming where gas production increased markedly from 1999 to 2008 (Fig. 1). Over the same period, wellhead prices more than doubled. The combination of production and price increases imply that the value of gas produced in each state more than quadrupled in less than a decade – clear evidence of a boom in natural gas (Table 1).

Estimates of the economic gains to local economies from a boom in natural gas extraction can inform policy makers considering how much incentive to provide (or disincentives to remove) to encourage extraction. The magnitude of gains is especially important for unconventional gas as it must be considered in light of possible negative externalities associated with extraction, including deterioration of roads caused by heavy trucks transporting water and possible health and environmental consequences from hydraulic fracturing. Some have used input–output models to project how gas development and extraction will affect local and state economies (Center for Business and Economic Research, 2008; Considine et al., 2010), however, the results of the models hinge on assumptions about economic multipliers and may deviate substantially from actual effects. To my knowledge, this is the first study to empirically estimate the local employment and income effects from the large expansion in natural gas extraction in several U.S. states in the last decade. In addition to studying aggregate economic outcomes, I explore how economic gains are distributed among the local population – a topic of interest since gains from extractive resource booms are sometimes skewed away from the poor (Brabant and Gramling, 1997).

I use gas deposit and production data combined with economic data to estimate how a substantial increase in the value of gas

☆ The views expressed are those of the author and should not be attributed to the USDA or the Economic Research Service.

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[1] Maps of the geographic distribution of unconventional reserves can be found on the website of the Energy Information Agency: http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm#pdf.

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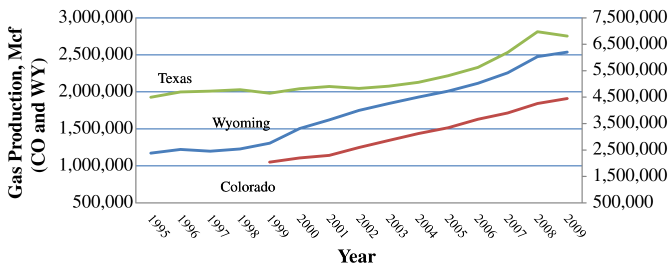

Fig. 1. The evolution of gas production in Colorado, Texas, and Wyoming (the left axis is for Colorado and Wyoming; the right axis is for Texas) Source: Colorado Oil and Gas Conservation Commission; Texas Railroad Commission; Wyoming Oil and Gas Conservation Commission, author's tabulation from county-level data.

production from 1998/99 to 2007/08 affected total employment, total wage and salary income, median household income, and poverty rates in the county of production in Colorado, Wyoming, and Texas. The empirics, which control for long-term growth trends and the potential endogeneity of gas production, provide the first ex-post analysis of the number of local jobs created by expanding gas production and are compared to ex-ante projections of the jobs created by developing the Fayetteville and Marcellus shale gas formations.

2. Resource extraction booms: theory and empirics

2.1. Theory

Corden and Neary (1982) developed a useful and influential model to understand the effects of a boom in an extractive export sector of a small open economy. As the extractive sector grows, it demands more labor, which increases wages. Some of the extra income from higher wages is spent on non-tradable goods like housing, whose prices increase because of their relatively inelastic supply. The non-booming export sector suffers as labor costs rises and the real exchange rate (price of non-tradables/price of tradables) appreciates, both of which lessen its competitiveness in the world market, an effect commonly referred to as Dutch Disease. Economists have applied the model to many national economies experiencing a boom in resource exports (e.g. natural gas in Norway, oil in Venezuela).

Applied to local economies within a national economy, the model can still be useful. How a boom affects the poverty rate, for example, will depend on how much labor the booming sector demands, how integrated the local economy is with larger markets, and the extent that local residents have the skills required by the booming sector. Thus, the economic impact of a particular boom is largely an empirical question, though a theoretical framework can be helpful in understanding how a boom can play out in a local economy.

Consider a rural economy with some unemployment and where residents commonly commute long distances to work. Depending on how much labor the booming sector demands, it could attract workers without increasing local wages. Local residents would stop commuting elsewhere and work locally for a wage similar to the one they previously earned further away, in which case welfare would increase (due to less time spent commuting) without an increase in wages or income. But if the booming sector offers work to people who could not previously find a job at the market wage, the boom would increase total income and likely decrease poverty.

Now consider a tight local labor market where residents do not have to commute far to find work. To attract workers, the booming sector must offer higher wages. As wages rise total income would increase and poverty would also likely decrease. It is important to note, however, that a poverty line defined in terms of local prices would change as living costs change. An influx of gas workers, for example, may push housing rental rates upward. If the cost of living increases more than the nominal income gain from greater employment, the cost-of-living adjusted poverty rate may increase.

If the booming sector requires special skills that local residents lack and are costly to acquire, then workers would have to come from outside the community (assuming that the cost of bringing in outside workers does not exceed the cost of training local workers). As skilled workers move to the community, total income generated increases. Per capita income would also likely increase, either because of rising wages across sectors or because the newly created jobs are higher skilled and therefore higher paying jobs.[2] Even if people living below the poverty line lack the skills to find jobs in the booming sector, spillovers into sectors like services (e.g. hotels and restaurants) would increase employment and perhaps wages for low income persons.

Resource booms likely have their largest economic effects on employment and wages, but other channels of economic stimulus include rents paid to private and public entities. In the U.S., most states that produce a lot of gas apply a severance tax on gas extracted. Gas companies drilling on private land also pay landowners for leasing the land and often a royalty based on how much gas they extract from the property. If land ownership is concentrated in the hands of a few, the gains from private resource rents would also be concentrated. Tax revenues from gas extraction, on the other hand, would likely have broader effects, either by lowering tax rates, increasing public services and investment, or both.

To summarize, a natural gas boom should increase total employment and income because of higher wages caused by a combination of greater demand for labor, an increase in the number of jobs (which may be filled by local or outside workers), and rent payments to private and public resource owners. Growth in aggregate employment and income, however, does not imply that median income will increase or that the poverty rate will decrease. The distribution of the gains will depend heavily on the skills of local residents and where they fall in the distribution of income, the extent that local and regional labor markets are integrated, and the size of spillovers into non-booming sectors.

Although this paper focuses on the short-term effects of a natural gas boom, a pertinent issue for policy makers is how to manage the cyclical aspect of extractive industries and possible negative spillovers into industries with high long-term growth potential. The long-term effects of a resource boom are less clear as resource-abundant countries appear to grow more slowly (Rodriguez and Sachs, 1999). Corden and Neary (1982) show how an export boom of an extractive sector could lead to de-industrialization as the boom erodes the competitiveness of the manufacturing sector in the world market. Alternatively, Sachs and Warner (1999) extend the booming sector model to show how a boom could be a catalyst for long-run growth when the non-tradable sector exhibits increasing returns to scale that can only be realized at certain market sizes. Both the industrialization and de-industrialization scenarios play out through a non-tradable goods sector, which may be small in most local economies in the U.S. that are well integrated with broader markets.

Table 1
Gas production and price increases for Colorado, Texas, and Wyoming, 1999–2008.

State	Percent increase, 1999–2008		
	Production[a]	Wellhead price[b]	Combined effect on the value of production[c]
Colorado	76	146	433
Texas	50	185	428
Wyoming	90	169	511

[a] Source: Colorado Oil and Gas Conservation Commission; Texas Railroad Commission; Wyoming Oil and Gas Conservation Commission, author's tabulation.
[b] Wellhead prices are from the Energy Information Agency.
[c] The combined effect on the value of production for Colorado, for example, is calculated as $1.73 \times 2.46 = 4.26$.

[2] An exception would be in a segmented labor market consisting of high skill-high wage jobs and low skill-low wage jobs. If the booming sector increases the share of low skill-low wage jobs in the economy, per capita income would fall.

2.2. Empirical studies

Much research explores how a country's economic dependence on natural resources affects its institutions and economic growth (see Stevens (2003) for an overview). This mostly cross-country work tends to find that dependence on natural resources is associated with lower long-term economic growth, an empirical pattern known as 'the resource curse'. Sala-i-Martin (1997), for example, finds that primary sector production is negatively correlated with growth, and that the result persists under many permutations of a basic econometric model of growth. The result also finds substantial support in the literature (Sala-i-Martin, Doppelhofer, Miller, 2004; Sachs and Warner, 1997, 2001).

The negative relationship between resource dependency and growth has political and economic underpinnings. States experiencing a resource boom often expand excessively in response to greater revenues and macroeconomic instability often follows (Auty, 2001; Gelb, 1988). Mehlum et al. (2006) find that more 'grabber friendly' institutions exacerbate the negative effect of natural resource abundance on GDP growth. Sachs and Warner (2001) find that natural resource economies tend to have higher price levels – a result consistent with the booming sector model where income generated by the booming sector boosts demand, increasing the price non-tradable goods (the price of tradable goods remain what they are on world markets). Feltenstein (1992) uses a General Equilibrium model to simulate the effects of an oil boom in Mexico and finds that it contracts the agricultural export sector by pulling labor from agriculture and by raising the price of non-tradable goods (real exchange rate appreciation). Other studies provide further evidence for how resource booms, or export booms in general, affect the domestic economy along the lines implied by the booming sector model. The coffee boom in Colombia, for example, was associated with a 30% appreciation of the real exchange rate that dramatically weakened the competitiveness of the non-coffee sector in world markets (Cuddington, 1989). Similarly, Fardmanesh (1991) finds that for five oil-dependent economies, the agricultural sector (a tradable good sector) contracted when oil exports boomed.

Though less extensive than the cross-country literature on resource booms or dependency, several studies explore resource extraction and local economies. Empirically, these studies exploit variation in resource-related activity across subnational units (and across time) and in doing so, hold constant many of the macroeconomic variables used in the cross-country growth literature. While no studies estimate the economic effects of natural gas production on local economies within the U.S. – the focus of this paper – existing studies explore the effects of booms over a range of natural resources and contexts. I start by focusing on oil, whose production process is similar to natural gas, and then broaden it to other commodities (coal, biofuels, and natural resources in general).

Michaels (2010) studies how being located above a major oil field affected economic growth in counties in the southern United States over a century (1890 to 1990) and finds that by the middle of the twentieth century oil counties had higher education levels and per capita income without having greater inequality than other counties. Instead of stunting the manufacturing industry, oil related activities stimulated population growth and was associated with more manufacturing employment per square mile, a finding consistent with versions of the Sachs and Warner (1999) Big Push model. Thus, while cross-country analysis suggests a negative relationship between resource dependence and economic growth, the opposite may hold within particular countries where a booming local economy may compose a small share of a larger regional or national economy, making it unlikely that the boom induces large increases in wages or other Dutch Disease effects.

Over a shorter period Marchand (2010) studies how labor markets in Western Canada respond to oil and gas price shocks. For the 1996 to 2006 boom, he estimates that total employment grew 6.5 percent more on an annual basis in treatment Census divisions (those with 10% or more of their total earnings from energy extraction in the base period) than in control divisions – a gain that was driven by expansion of the energy sector and spillovers from energy into sectors like services. Likewise, earnings and earnings per worker grew 11.5% and 4.9% more, and the number of persons living in poverty decreased 10.2% more. The effects are large but reasonable since the energy sector composes a large share of the economy in many areas of Western Canada.

Caselli and Michaels (2009) study how oil output in Brazil affects local economic growth, composition, and municipal revenues and expenditures from 2000 to 2005. They find that oil production had almost no spillovers into the non-oil economy. And while they find a strong relationship between oil output and local government revenues (via royalities), the effect on local living standards as measured by indicators like poverty and household income, suggest that little of the revenue generated by greater oil output reached the local population. The contrast with Michaels (2010) and Marchand (2010) could be interpreted as supporting Mehlum et al. (2006) who find that the quality of institutions can shape the economic effects of natural resource industries.

Black et al. (2005) estimate how the coal boom and bust in the 1970s and 1980s affected counties in Kentucky, Ohio, Pennsylvania, and West Virginia. They find that during the boom employment grew two percentage points faster in coal counties than in non-coal counties and earnings grew five percentage points faster. Each additional mining job generated .25 local sector jobs and no traded-sector jobs, a result consistent with the booming sector model. Furthermore, not all gains were lost during the bust. Regarding the distribution effects, the number and percent of families in poverty decreased substantially during the boom, but in the bust period poverty returned to pre-boom levels.

As with the debate about natural gas development in the U.S., proponents of biofuels have pointed to potential employment provided by the industry. Blanco and Isenhouer (2010) look at biofuels and employment per capita in counties in the U.S. corn belt and find a statistically significant effect of very small economical magnitude: a 1% increase in ethanol production increased employment per capita by .007% in the average county. The small effect is likely because ethanol is not a labor intensive industry and, most importantly, the value of production in the average county is small – around $10 million at 2006 prices. A 1% increase is then equivalent to only $100,000. The other studies discussed here estimate the effects of larger absolute changes. Black et al. (2005), for example, look at how a more than doubling in coal prices affected employment and earnings in counties who, on average, derived a quarter of their total earnings from coal mining prior to the boom.

In contrast to the largely positive economic effects of energy production found by the previous studies, Papyrakis and Gerlagh (2007) find a negative effect of dependency on natural resources and growth across U.S. states. Using the share of gross production from natural resource industries (agriculture, forestry, fishing or mining) as the key independent variable, they find that a 1% increase in income from natural resources is associated with a decrease in annual growth rate of .047 for the period 1987 to 2000. It is important to note that the effects of a commodity boom may differ from how an economy's initial dependence on natural resource industries affects long-run growth. While higher output prices should clearly stimulate economic activity in producing regions, areas specializing in natural resources may still grow more slowly over the long run.

A review of the literature reveals that the economic effects of growth in a natural resource industry can vary by commodity, context, and time horizon. This paper builds on the literature by providing the first empirical estimates of how a large expansion in natural gas production in several U.S. states in the last decade affected income and employment, including the number of local jobs created per million dollars of gas extracted – a number that permits comparisons with existing projections from input–output models. In addition, the data permit estimating changes to median household income and the poverty rate, thus providing insight into the distribution of income gains from greater gas extraction.

3. Data and sample description

The initial total sample includes all counties in Colorado, Texas, and Wyoming, of which there are 338 after dropping two counties in Wyoming with missing data. The states were chosen because they are major on-shore producers of natural gas with readily available data on gas production at the county level over time. Furthermore, all three states experienced a sustained expansion in gas production from 2000 onward, which simplifies applying a triple difference estimation approach for a data set that pools counties across states. However, it is important to note that in many aspects, like population density, Colorado, Texas, and Wyoming may not be representative of other states. Consequently, care should be taken when applying the results elsewhere.

Data on poverty and median household income are from the Census Bureau's Small Area Income and Poverty Estimates program. The program combines administrative and survey data from multiple sources to provide reliable single year estimates at the county level.[3] County-level economic data like employment and wage and salary income are from the Bureau of Economic Analysis. I use wage and salary income instead of total personal income, which includes sources like transfer payments and capital gains, because it comes from information collected from businesses for unemployment insurance tax purposes and is arguably more reliable.

I obtained gas production data at the county level from the websites of the state agencies charged with overseeing oil and gas development (Colorado: Colorado Oil and Gas Conservation Commission; Texas: Texas Railroad Commission; Wyoming: Wyoming Oil and Gas Conservation Commission). GIS data on unconventional gas formations and state-level prices for gas at the wellhead are from the Energy Information Agency. [4] Production data are essential for identifying which counties experienced a boom in gas extraction. GIS data aid in identifying the effect of a gas boom by providing geological information to be used as an instrument for whether a county experienced a gas boom.

Looking at the change in gas production over the period 1998/99–2007/08[5] reveals which counties experienced a boom. Graphing every fifth percentile of the distribution of the county-level change in production shows that about 25% of counties saw some decrease in gas production, 50% saw virtually no change, and about 25% saw an increase (Fig. 2). I define a boom county as a county in the top 20% for the change in gas production. These counties tend to be geographically clustered as shown by Fig. 3. If gas-related economic activity spills into a county with little or no gas production, it will lead to an underestimation of the effect of the boom. In the language of controlled experiments, spatial spillovers mean that some 'control' counties receive treatment. To avoid this problem, I follow Black et al. (2005) and exclude non-boom counties that share a border with a boom county, which reduces the sample from 338 to 209 counties

The distribution of population among counties in the three study states is skewed, with counties that are home to major cities having dramatically higher population than most counties. Shocks to high

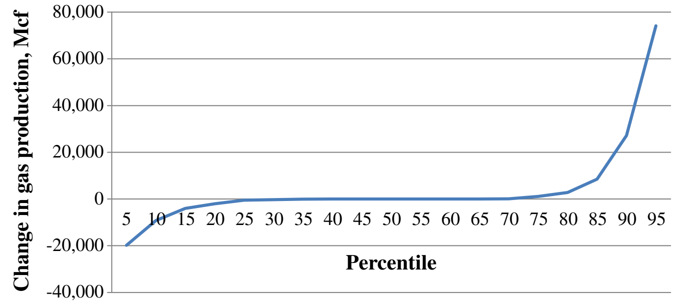

Fig. 2. The distribution of the change in gas production (1998/99–2007/08) for counties in Colorado, Texas, and Wyoming (N = 338).

population counties will cause large changes in absolute employment and income relative to smaller counties. To avoid having a few high population counties exert excessive influence on the regression results, I drop counties with a population greater than the 90th percentile of the initial sample of 338 counties – all of which correspond to metropolitan counties (metropolitan counties are those with cities of more than 50,000 people or where a quarter of the labor force works in a nearby metro county). Trimming extremely high population counties reduces the sample from 209 to 188 counties, with 61 and 127 boom and non-boom counties, and is the main sample used for analysis.

I compare the mean values of select variables for boom and non-boom counties and test if they are statistically different from each other. All variables except the change in gas production are from 1998, shortly before gas production began a substantial expansion in all three states. From 1998/99 to 2007/08, the average boom county saw the value of gas production increase by $757 million dollars compared to a $10 million dollar increase for non-boom counties. Boom counties produced more gas in 1998 than non-boom counties and understandably had a greater share of earnings from the mining sector (14% compared to 4%). Thus, in the early 1990's, counties that were to experience a large expansion in gas production were already more specialized in extractive industries. This is unsurprising since unconventional gas reservoirs, which were responsible for much of

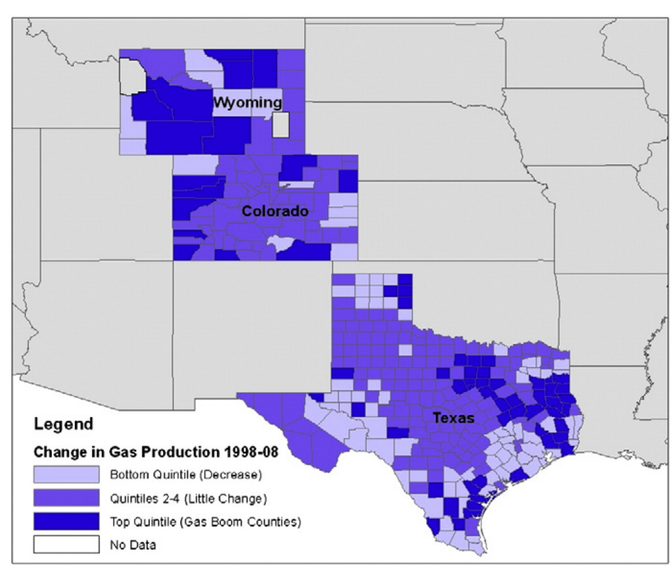

Fig. 3. The location of boom counties.

[3] For more information on how the Census Bureau calculates poverty and household income visit: http://www.census.gov/did/www/saipe/.

[4] The GIS gas formation data is available at the EIA website: http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm#shaleplay. Price series data for each state is available at: http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.

[5] Because gas production can be erratic, I average gas production over two years to calculate the pre-boom and boom production levels. Thus, the change in gas production 1998/99-2007/08 is calculated as $\frac{1}{2}*((\text{Production2007}+\text{Production2008})-(\text{Production1998}+\text{Production1999}))$.

the increase in production, often occur close to conventional gas formations.

Aside from greater gas production and dependence on mining, in 1998 boom counties had higher total employment and wage and salary income than non-boom counties, part of which is driven by the higher population of boom counties, though boom counties also had slightly higher median household income. Otherwise, boom counties had poverty rates, population densities, and dependence on the manufacturing and construction sectors such that the difference in means between boom and non-boom counties is not statistically different from zero (Table 2). Furthermore, the population density of adjacent counties was similar for boom and non-boom counties, suggesting that boom counties are not more remote than other counties.

As a first attempt to look for effects of the gas boom, I graph the difference between boom and non-boom counties in the logarithm of total employment and total wage and salary income from 1993, well before the boom, till 2008. Fig. 4 shows that boom counties had slightly higher employment and wage and salary income, but that the difference was fairly constant from 1993 to 2000. Around 2000, when gas production started to increase, the differences in logs between boom and non-boom counties increased markedly; from 1999 to 2007 it increased by 19% for employment and 27% for wage and salary income. Thus, a casual look at the data suggests that boom counties saw greater economic growth relative to non-boom counties over the period when gas production increased substantially.

4. Empirical model and estimation

Estimating the economic effects of resource booms or resource specialization can be done in various ways, with some studies looking at effects on the level of economic activity (Caselli and Michaels, 2009; Michaels, 2010), annual changes (Black et al., 2005), or average growth over a period (Marchand, 2010; Papyrakis and Gerlagh, 2007).

Table 2
Comparing boom and non-boom counties.

Variable	Non-boom counties ($n=127$)		Boom counties ($n=61$)		p value[a]
	Mean	SD	Mean	SD	
Gas production ($ millions), 1998/99	16.2	48.7	135.2	214.8	0.000
Change gas production ($ millions), 1998/99–2007/08	10.0	46.3	756.5	1051.8	0.000
Employment	10,235	14,337	14,803	15,662	0.049
Wage and salary income ($ millions), 1998	208	347	330	394	0.032
Median household income, 1998	39,029	9967	41,527	8695	0.096
Poverty rate, 1998	17.8	6.5	16.6	6.2	0.225
Total Population, 1998	20,018	24,722	30,214	29,493	0.014
Population density (persons per square mile)	0.987	0.037	0.989	0.046	0.695
Agriculture share of earnings 1998	0.025	0.049	0.012	0.019	0.050
Mining share of earnings 1998	0.039	0.083	0.142	0.181	0.000
Manufacturing share of earnings, 1998	0.081	0.070	0.090	0.064	0.418
Construction share of earnings, 1998	0.114	0.130	0.115	0.113	0.951
Population density of contiguous counties, 1998[b]	0.991	0.028	0.987	0.022	0.294
Per capita wage and salary income of contiguous counties, 1998[b]	1.421	0.358	1.507	0.330	0.115

Monetary amounts are in 2007 dollars.
[a] This is p value associated with testing if the means are different from each other where the null hypothesis assumes that they are not different.
[b] The variables referring to contiguous counties are calculated by average values across all contiguous counties.

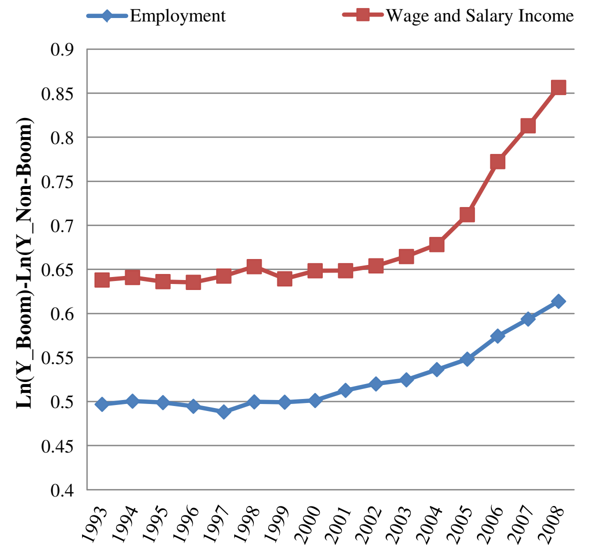

Fig. 4. Difference in the logarithm of total employment and wage and salary income, boom and non-boom counties, 1993–2008 (N = 188).

In the case of gas extraction, it is unclear if the bulk of economic activity generated by an increase in production would occur when wells and infrastructure are built, when most production occurs, or later when gas proceeds like royalties and tax revenues start to flow. To capture the cumulate effect of a sustained increase in gas production, I focus on changes in economic outcomes over several years. One approach is to look outcomes before (1999) and after (2007)[6] production substantially expanded. Looking at the difference in changes in employment across boom and non-boom counties constitutes a difference-in-difference approach commonly used in the policy evaluation literature (see Angrist and Pischke, 2009, for a discussion of noteworthy examples).

The difference-in-difference approach eliminates time invariant additive confounding factors but it does not control for the possibility that boom counties were growing faster (or slower) prior to the boom. In contrast, differencing growth over the boom period with growth in the pre-boom period, 1993–1999,[7] a triple difference approach, calculates how boom counties grew over the boom period relative to their trend in the pre-boom period and compares it with the same outcome for non-boom counties.[8] The triple difference approach can be implemented by defining the dependent variable y_i as

$$y_i = (y_{i2007} - y_{i1999}) - (y_{i1999} - y_{i1993}) \tag{1}$$

Regressing y_i on a constant and an indicator variable for a boom county would provide the average effect of being a boom county on y_i and is robust to boom counties having a different growth trend prior to the boom. An even more robust specification would be to include control variables that allows counties with different characteristics to

[6] I use 2007 instead of 2008 as the end point for the boom period because of the macroeconomic shock to the U.S. that occurred in 2008.
[7] I use 1993 as the start of the pre-boom period because data on median household income and the poverty rate were not available for 1992, which, if used, would have made the boom and pre-boom periods of equal duration (8 years).
[8] Another empirical approach would be to use the year-to-year change in employment, for example, as the outcome variable and regress it on a boom county variable, a boom period variable, and the interaction between the boom county and boom period variable. This panel approach is not taken because the instrumental variable used for identification is time invariant. Defining the dependent variable as in Eq. (1) converts the model into a cross-sectional form while retaining the advantage of the triple difference approach, namely allowing for different growth trends for boom and non-boom counties.

have different outcomes in y_i. This is the empirical approach taken, with the full specification being

$$y_i = \alpha + \beta(Boom\,County) + \delta_1 X_{i92} + \delta_2 C_{n(i)92} + \theta_{s(i)} + \varepsilon_i \quad (2)$$

A county's initial conditions are captured in X_{i93}, as are the characteristics of neighboring counties ($C_{n(i)92}$) in the initial period, and a state fixed effect ($\theta_{s(i)}$). I estimate Eq. (2) for four outcomes: total employment, total wage and salary income, median household income, and the poverty rate.

The literature contains diverse approaches to including control variables in models of resource booms and economic growth. Black et al. (2005) only control for state and time effects and their interaction. Caselli and Michaels (2009) also include geographic variables like longitude and latitude and the distance to the state and federal capital. Michaels (2010) includes a similar set of controls (longitude, latitude, distance to ocean) plus variables like the fraction of land cultivated and an indicator for urban population. While geographic location may matter for long-term growth trajectories, growth over a particular decade likely reflects the structure of the economy in the baseline year and how subsequent shocks interact with this structure. For example, how the housing boom and bust affects a county's economy will depend on the relative size of the construction sector. To control for such possibilities, I include a county's initial population density, per capita wage and salary income, and the percent of total earnings accounted for by the agricultural, mining, manufacturing, and construction sectors. To avoid confounding geographic characteristics with the effects of being a boom county, I also control for the average population density and per capita income in adjacent counties in the initial period.

It is possible that counties can influence whether or not large scale gas extraction occurs in their area. Boxall et al. (2005) find that in Alberta proximity to gas wells lowers property values. County residents may fight gas drilling to avoid a possible decrease in property values or quality of life, with wealthier counties perhaps the best equipped to win the fight. Similarly, gas companies may target gas formations in counties based on characteristics not observed by the econometrician and that affect the outcome of interest, thereby introducing potential bias. One approach to address the endogeneity of resource booms is to classify counties based on geological characteristics such as reserves or oil and gas (Michaels, 2010). The method has intuitive appeal since few variables are as outside of human control as initial geological endowments. Furthermore, unlike visible attributes of the land (rivers and mountains), gas deposits are not visible, so it would be unlikely that certain types of people or business activities would tend to locate near them.

Good instruments should be correlated with the variable that they are instrumenting for and uncorrelated with the error term in the outcome equation – in this case, ε. I use the percent of the county covering an unconventional gas formation (shale, tight, or coalbed methane) as an instrument for being a boom county (*Gas Boom*). For a model with one possibly endogenous regressor and one instrument (the just identified case), the Two-Stage Least Squares estimate is approximately unbiased (Angrist and Pischke, 2009). However, imprecision and bias may occur in the second stage if the instrument is only weakly correlated with the endogenous regressor. Staiger and Stock (1997) suggest a rule of thumb for one endogenous regressor and one instrument, the F-stat for the null hypothesis that the instrument's coefficient is jointly equal to zero should exceed 10. Stock and Yogo (2005) provide a formal interpretation of this rule of thumb – an F-stat greater than 10 roughly corresponds to the 5% critical value of the hypothesis that the bias of the IV estimate is less than 10% of the bias of the OLS estimate. However, Stock and Yogo (2005) also find that weak instruments distort the size of Wald test based on the IV estimates. Their simulations suggest that to avoid size distortion in the case of one instrument and one endogenous regressor, the F test should exceed 16.38.

To test for instrument strength, I regress *Boom County* on the instrument (*Percent Gas*) and all control variables included in Eq. (2) (see Table 3 for results). The F-stat for the restriction that the coefficient on *Percent Gas* is zero is 31.31, well above the weak instrument threshold suggested by Stock and Yogo to avoid bias and test size distortion. Estimating Eq. (2) while instrumenting for *Boom County* provides a check on the OLS results that is robust to the endogeneity of *Boom County*. Tables 4 and 5 present the OLS and IV results for the four outcomes studied. Robust standard errors are reported in parenthesis.

5. Results

The OLS and IV point estimates suggest that being a boom county is associated with higher growth in total employment and wage and salary income, however, the effects suggested by IV are larger than the OLS estimate and, unlike the OLS results, are statistically distinguishable from zero (Table 4). When looking at median household income, the OLS and IV point estimates are positive and of similar magnitude but only the OLS estimate is statistically significant. Both models fail to find precise effects of being a boom county on the poverty rate. The results also suggest that counties where mining composed a larger share of the economy saw greater growth in employment, wage and salary income, and median household income. In contrast, counties adjacent to high population density counties saw weaker employment growth.

The most policy relevant question concerns the magnitude of the estimated effects, which raises the question of which estimate to trust, OLS or IV. If an exogeneity test fails to reject the exogeneity of *Boom County*, the OLS estimates are preferred on the grounds of efficiency (greater precision). Where the exogeneity of *Boom County* is rejected, IV should used on the grounds that it is unbiased. To test for exogeneity, I use the Durbin–Wu–Hausman test. First, I regress *Boom County* on the excluded instrument, and the control variables and obtain the residuals. Then, I regress the outcome variable on *Boom County*, the control variables, and the residuals from the previous regression. If the coefficient on the residual is not statistically different from zero, then I fail to reject the null hypothesis that the OLS and IV estimates are the same. The p values for testing the exogeneity of *Boom County* for the four models (total employment, total wage

Table 3
Instrumental variable first stage results.

Variable	Boom county
Percent gas	0.457***
	(0.082)
Per capita income, 1992	0.006
	(0.005)
Population density, 1992	−0.114
	(0.309)
Agriculture share of earnings 1992	−0.492
	(0.453)
Mining share of earnings 1992	0.621**
	(0.250)
Manufacturing share of earnings, 1992	−0.090
	(0.536)
Construction share of earnings, 1992	−0.018
	(0.237)
Population density of contiguous counties, 1992	0.477
	(0.448)
Per capita income of contiguous counties, 1992	0.189**
	(0.088)
Texas	−0.109
	(0.112)
Wyoming	0.392***
	(0.137)
Intercept	−0.425
	(0.369)
Observations	188
Adjusted R-squared	0.280
F-statistic for *Percent Gas* = 0	31.31

Robust standard errors in parenthesis. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4
Effects of a gas boom on total employment and wage and salary income, OLS and IV (LHS variable = $\Delta Y_{2007-1999} - \Delta Y_{1999-1993}$).

Variables	Employment		Wage and salary income	
	OLS	IV	OLS	IV
Boom county	510	1780**	23	69**
	(364)	(820)	(15)	(31)
Per capita income, 1992	−31	−38	1.2	1.0
	(40)	(38)	(0.8)	(0.8)
Population density, 1992	455	359	−6.6	−6.9
	(921)	(973)	(43)	(43)
Agriculture share of earnings 1992	2950	4448*	53	108
	(2071)	(2444)	(62)	(74)
Mining share of earnings 1992	2537***	1530	149***	113**
	(880)	(995)	(57)	(57)
Manufacturing share of earnings, 1992	2267	2255	82	82
	(1919)	(1889)	(72)	(72)
Construction share of earnings, 1992	626	499	23	19
	(968)	(1009)	(36)	(40)
Population density of contiguous counties, 1992	−4033**	−3868**	−114	−108
	(1817)	(1830)	(78)	(76)
Per capita income of contiguous counties, 1992	109	−129	19	10
	(557)	(601)	(21)	(21)
Texas	853**	791**	21	19
	(418)	(403)	(19)	(18)
Wyoming	3523***	2931***	187***	165**
	(939)	(958)	(68)	(67)
Intercept	2017	2027	46	46
	(1813)	(1771)	(75)	(73)
Observations	188	188	188	188
Adjusted R-squared	0.126	0.047	0.268	0.218

Robust standard errors in parenthesis. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.
[a] *Wage and Salary Income* is in terms of millions of 2007 dollars.

and salary income, median household income, and the poverty rate) are .07, .07, .92, and .56. Based on the exogeneity test results, I emphasize the IV estimates for the first two models and the OLS estimates for the last two.

Table 5
Effects of a gas boom on median household income and the poverty rate, OLS and IV (LHS variable = $\Delta Y_{2007-1999} - \Delta Y_{1999-1993}$).

Variables	Median household income		Poverty rate	
	OLS	IV	OLS	IV
Boom county	1976***	1809	−0.345	−0.987
	(753)	(1689)	(0.544)	(1.145)
Per capita income, 1992	90*	91*	0.003	0.006
	(50)	(51)	(0.046)	(0.048)
Population density, 1992	10,097**	10,109**	−7.917*	−7.869**
	(4194)	(4040)	(4.139)	(3.850)
Agriculture share of earnings 1992	25,725**	25,528**	−0.935	−1.692
	(10,789)	(10,649)	(10.458)	(10.253)
Mining share of earnings 1992	12,435***	12,567***	−2.832	−2.323
	(4057)	(4226)	(2.258)	(2.201)
Manufacturing share of earnings, 1992	−6153	−6151	−9.837**	−9.831**
	(7211)	(6995)	(4.636)	(4.533)
Construction share of earnings, 1992	−1492	−1475	5.108**	5.172**
	(2791)	(2695)	(2.205)	(2.141)
Population density of contiguous counties, 1992	14,987**	14,965**	−5.448	−5.531
	(6110)	(5978)	(5.858)	(5.632)
Per capita income of contiguous counties, 1992	−622	−591	−1.094	−0.974
	(1131)	(1177)	(0.760)	(0.787)
Texas	901	909	−1.240	−1.208
	(1168)	(1139)	(1.205)	(1.172)
Wyoming	6791***	6869***	−3.591***	−3.292***
	(2143)	(2115)	(1.188)	(1.258)
Intercept	−33,302***	−33,303***	17.416***	17.410***
	(4312)	(4187)	(4.404)	(4.263)
Observations	188	188	188	188
Adjusted R-squared	0.503	0.503	0.206	0.201

Robust standard errors in parenthesis. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The IV results imply that for the period 1999 to 2007 the gas boom was responsible for adding on average 1,780 more jobs and $69 million more in wage and salary income to county economies. In the average boom county, the value of gas production increased by $757 million from 1998/99 to 2007/08. Thus, a million dollars in additional gas production was associated with 2.35 more jobs. Put differently, the annual number of jobs created was 223, which is 1.5% of total employment in boom counties in 1998. For wage and salary income, each million dollars in gas generated about $91,000 in wage and salary earnings, roughly 9% of the value of gas production. The annualized increase in wage and salary income was $8.62 million, or 2.6% of wage and salary income in boom counties in 1998.

The estimates provide evidence that the income gains were skewed away from lower income households. According to the OLS estimate in the median household income model, which is statistically indistinguishable from the IV estimate, the gain in median household income was $1976. The annual gain ($1976 divided by 8 years) represents a 0.59% increase over the 1998 level for boom counties. The increase in wage and salary income over the 1998 level was more than four times larger (2.6%), suggesting that a larger share of the wage and salary income generated by the boom went to households in the upper half of the income distribution. Furthermore, the estimates for the effect on the poverty rate, though negative, are statistically indistinguishable from zero for both OLS and IV models.

While the empirical approach used identifies the causal effects of being a boom county under weak assumptions, as a robustness check I re-estimate the model in two different ways. In the first check, I add five control variables to the base model: wage and salary compensation per job in contiguous counties in 1992; the percent of the county that is rural in 1993; an indicator variable whether the federal government owns at least 30% of the county's land; an indicator for whether at least 40% of the labor force work outside the county; and an indicator for whether at least 25% of total personal income (1987–89 annualized average) in the county comes from transfer payments. The last three variables are from county typologies developed by the Economic Research Service of the USDA and are based on data from 1989.[9] For the second check, I drop all metropolitan counties instead of trimming counties based on having a population greater than the 90th percentile of the original total sample.

Table 6 presents the OLS and IV point estimates and standard errors for *Boom County*. Adding more control variables or using only non-metro boom and non-boom counties gives qualitatively similar results. Adding control variables slightly decreases the IV estimates for total employment and wage and salary income while using only non-metro counties leads a more substantial decrease, though the statistical significance remains the same. When looking at median household income, the first check decreases the OLS effect by around $275 but the second check increases it by a similar amount. Both models fail to detect any statistically significant effect of *Boom County* on the poverty rate.

6. Discussion

Several reports have used input–output models to estimate the employment effects of greater natural gas production. While input–output models permit an ex-ante assessment of the economic impacts of expansion of a particular industry, the projections hinge on assumptions about multipliers between economic sectors and a lack of supply constraints. It is therefore important to assess such projections with empirical estimates.

The Center for Business and Economic Research at the University of Arkansas used the IMPLAN input–output model to project the economic effects of developing the Fayetteville Shale formation. The

[9] For more information on these variables, see http://www.ers.usda.gov/Briefing/Rurality/Typology/Typology1989/.

Table 6
Results from robustness checks.

			Employment	Wage & salary income	Median hhld. income	Poverty rate
Adding covariates	OLS	Coef.	580	27*	1700**	−0.832
		SE	(423)	(16)	(796)	(0.609)
	IV	Coef.	1606**	65**	1809	−1.511
		SE	(806)	(31)	(1662)	(1.176)
Using only non-metro counties	OLS	Coef.	295	19	2193***	−0.186
		SE	(263)	(15)	(805)	(0.625)
	IV	Coef.	1051**	51**	1352	−1.330
		SE	(434)	(21)	(1486)	(1.095)

Robust standard errors in parenthesis. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

study estimated that 88.8 billion cubic feet in gas production in 2007 would directly and indirectly create 9533 jobs in the state. According to the Energy Information Agency, the price of natural gas at the wellhead in Arkansas was $6.61 dollars per thousand cubic feet in 2007, meaning that the value of gas production supposed by the study was about $586 million. I estimate that each million dollars in gas production creates 2.35 jobs ($757 million dollars divided by 1780 jobs), which implies that $586 million dollars in gas production would create about 1377 jobs – less than a fifth of the report's estimate.

Also using the IMPLAN model, Considine et al. (2010) estimate the impacts of developing the Marcellus Shale on the Pennsylvania economy. They estimate that 44,098 jobs associated with the Marcellus Shale were created in 2009, a year when natural gas output was around 119 billion cubic feet in natural gas equivalents or about $929 million dollars (at 7.81 dollars per thousand cubic feet – the wellhead price for Pennsylvania in 2009). According to my estimates, the jobs created would have been around 2183. A key reason for the discrepancy is that their model depends heavily on the $4.5 billion dollars in planned spending by Marcellus producers. Much of this planned spending is associated with building the capacity to exploit the Marcellus shale, which is why more jobs might be created than what current production would imply.

One reason for the difference between empirical estimates and the projected impact from input–output models is that the input–output studies cited calculated the number of jobs created across the entire state. In contrast, my estimates are based on the effect of gas production on jobs in the county where production occurs and therefore ignores jobs that gas production in one county creates in another county. But for county spillovers to account for the difference in estimated impacts, most of the jobs created by the natural gas industry would have to be outside of the county where production occurs. For the Arkansas study, 85% of the jobs would have to be outside of the county of production; for the Penn State study, the number is 95%. Furthermore, the estimates found in this study may incorporate some of the local spatial spillovers associated with gas production. More than 40% of the counties adjacent to boom counties were boom counties themselves in contrast to the non-boom counties used in estimation which had no boom counties adjacent to them. Because counties with large increases in gas production are likely adjacent to counties that also had a large increase, the estimated effects probably capture some of the spillovers.

There are two caveats to the finding that expansion in gas production yields modest economic gains. First, oil and gas booms often attract transitory (yet specialized) workers. To the extent that some of the employment and earnings of temporary workers drawn from other counties is not captured in the statistics of the county where the gas is produced, the estimated effects are lower bound estimates. Secondly, tax revenues from gas production help fund state governments and can benefit residents via lower taxes or greater public services and investment. Between 2005 and 2010, for example, taxes on natural gas production generated between .8 and 3.2% of the revenue for the Texas state government (Window on State Government, 2011).

Furthermore, while this study's estimates of economic impacts are much smaller than the projections from input–output models, the estimated effects are modest but not negligible. Greater employment and wage and salary income growth of 1.5 and 2.6% are economically important gains and cannot be ignored. To put in perspective, Black et al. (2005) found that during the coal boom in the 1970's, which involved a more than doubling of mining earnings in the coal producing states of the study, coal counties had employment and earnings growth that was 2.0 and 5.0% faster than in non-coal counties.

7. Conclusion

This study's ex-post analysis of a gas boom in Colorado, Texas, and Wyoming can inform policy debates in states where gas production is beginning to expand. As noted in the Introduction, the Marcellus Shale covering large parts of Pennsylvania and New York is in the early stages of development, with production in a few counties approaching substantial levels. In the current economic and political context of high unemployment and large public sector deficits, more jobs and greater tax revenue from exploiting natural gas resources appeals to political leaders and their constituents. Though estimated for more thinly populated western counties, the absolute number of local jobs created per million dollars in gas production (2.35 jobs) provides a reference point for policy debates in states with growing natural gas industries. The ex-post estimates from Colorado, Texas, and Wyoming can complement ex-ante economic analysis using input–output models, which in the case of the Fayetteville and Marcellus shale may overestimate the number of jobs created by greater gas production.

Defensible estimates of employment and income gains can complement other indicators relevant to policy debates involving natural gas extraction. A comprehensive assessment of the costs and benefits of gas extraction would consider public and private economic benefits and costs, including economic, health, and environmental costs associated with extraction. Costs to consider include fixing roads damaged by greater use (National Park Service, 2009) and decreased property values in some areas Boxall et al. (2005). Perhaps more importantly, injecting a water-chemical mix into the ground to 'frack' unconventional deposits may involve costs that are not yet clear. Injected water that returns to the surface must be properly managed, and waste water treatment plants designed without such waste in mind may be unable to handle fluids from gas operations (Massachusettes Institute of Technology, 2011; Yoxtheimer and Gaudlip, 2011). Defensible estimates of costs combined with measures of economic benefits can inform policy debates like whether and how much state governments should tax gas extraction.

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